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ORIGINAL ARTICLE

Robot guidance for percutaneous minimally invasive placement of pedicle screws for pyogenic spondylodiscitis is associated with lower rates of wound breakdown compared to conventional fluoroscopy-guided instrumentation

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Abstract Postoperative wound healing can pose a problem in patients undergoing instrumented surgery for pyogenic spondylodiscitis. Robotic guidance allows the minimally invasive placement of pedicle screws in the thoracolumbar spine. We assessed whether using this technique to perform minimally invasive surgery had an impact on wound healing in patients with pyogenic spondylodiscitis when compared to conventional open fluoroscopy-guided surgery. We reviewed charts of 206 consecutive patients who underwent instrumentation for pyogenic spondylodiscitis. The need for wound revision was the primary outcome measure. Patient variables and comorbidities as well as surgical technique (robotic versus fluoroscopy-guided) were analyzed. We also compared fluoroscopy times between the two groups. Multivariate regression analysis was performed to identify predictors of wound breakdown. A total of 206 patients underwent surgery for spondylodiscitis. Robotic surgical assistance was used for percutaneous instrumentation in 47.6% of cases (n = 98). Wound healing problems requiring revision occurred in 30 out of 206 patients (14.6%). Univariate analysis revealed a potential association of wound breakdown with (1) robotic technique, (2) age > 70 years, and (3) the presence of methicillin-resistant *Staphylococcus aureus*. After multivariate correction however, only robotic technique retained significance with an odds ratio of 0.39 (CI 95% 0.16–0.94; p = 0.035). Wound revision was required in eight out of 98 patients (8.1%) in the robot group and 22/108 (20%) in the conventional surgery group. Fluoroscopy times were significantly lower in the robot group with a mean of 123 ± 86 s in comparison with a mean of 157 ± 99 s in the conventional group (p = 0.014). While initially designed to improve the accuracy of pedicle screw placement, robot-assisted minimally invasive technique had a tangible effect on both radiation exposure and the rate of wound breakdown in patients with pyogenic spondylodiscitis in our large single-center study.

Keywords Spine instrumentation · Spondylodiscitis · Robotic surgery · Spinal fusion · Methicillin-resistant *Staphylococcus aureus*

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Introduction

Spondylodiscitis has an incidence of about 1:100,000 to 250,000 person years [11]. Due to its rarity and the heterogeneity of the disease with often considerable delays until diagnosis, no prospective data exist to guide its management. Some groups advocate a trial of antibiotics with immobilization [1] supplemented by surgery in case of progression of discitis [29]. When choosing conservative management, decompression surgery is reserved for cases with epidural abscess and impending neurological impairment. Pedicle screw instrumentation with or without anterior debridement is reserved for cases where discitis has progressed sufficiently to induce symptomatic macroinstability. On the other end of the spectrum, surgical treatment may be used in all cases to support antibiotic treatment. Although controversial, [8] some groups including ours routinely perform instrumentation in patients with pyogenic spondylodiscitis [16]. Instrumentation allows healing and fusion of the diseased segment while reducing complications of prolonged bedrest [27]. Despite the established role of surgery, the impact of surgical complications and potential technical refinements to minimize them remain understudied. Wound infections are an important complication leading to prolonged stay and morbidity after spine surgery for non-infectious causes with rates ranging from 0.4 to 8.7% [2] and up to 15% in instrumented cases [3]. In patients with preexisting infectious disease, the rates of wound healing problems are likely higher [7]. There is retrospective evidence to suggest that minimally invasive technique has a beneficial effect on the rate of wound breakdown in degenerative spinal disease. One study cites rates of surgical site infection of 7% for open versus 4.6% for minimally invasive technique [17]. However, no study specifically addressed the rate of wound healing problems in patients with pyogenic spondylodiscitis. Therefore, the impact of minimally invasive technique on wound healing in this patient population—which is particularly prone to complications—is unknown.

Robotic technique has been used routinely to guide implantation for close to a decade. Pedicle screws placed with the aid of robotic systems have accuracy rates which are comparable to those placed with expert-level open technique in retrospective [25] and prospective [15] series. Moreover, robotic pedicle screw placement reduces intraoperative radiation time [23]. Most importantly for surgeons not yet familiar with minimally invasive technique, robot-guided surgery allows the percutaneous placement of screws which, by means of reducing wound surface, may contribute to minimizing wound healing problems. This study was conducted to assess the rate of wound revision after instrumented surgery for discitis and to identify factors predicting poor wound healing which might help in risk-stratification prior to surgery.

Material and methods

This retrospective analysis was conducted in accordance with the Helsinki Declaration and its later amendments and in keeping with the recommendations of the ethical committee and institutional review board of the Georg August University of Göttingen. Charts of patients operated for pyogenic spondylodiscitis between 2007 and 2016 with pedicle screw instrumentation were included in the analysis.

The diagnosis of spondylodiscitis was based on largely concordant clinical, radiological, and laboratory findings [28]. Clinical findings include vertebral pain on percussion and neurological impairment due to epidural compression. Computed tomography typically showed erosive changes to the endplates. Contrast enhancement on magnetic resonance imaging as well as hyperintensity on tau inversion recovery sequences and epidural or paraspinal abscess was used to confirm the clinical diagnosis of spondylodiscitis. Elevated C-reactive protein levels were used to provide additional support for the diagnosis since leukocyte counts are less sensitive for the presence of spondylodiscitis.

Patients were operated on using robotic technique or conventional technique for logistic reasons or at the discretion of the treating surgeon. The robot system at our department is available only for one robotic surgery per day. Therefore, in case of multiple surgeries on any given day, the robot was only used on one occasion. We collected data on the presence of epidural abscess and whether a decompression was performed in addition to instrumentation. Surgery was performed using two techniques: We either performed a large midline incision and anatomical exposure of entry points under lateral fluoroscopic guidance, or employed percutaneous, minimally invasive technique with small stab incisions using robot-assistance using the Mazor Spine Assist surgical assistance system (Caesarea, Israel) as described elsewhere [13]. We retrieved the variables sex, age (>70 years as a cutoff for subgroup analysis), obesity (body mass index > 30), surgical technique (robotic percutaneous versus open conventional) with and without decompression, increased white blood cell count (WBC > 11,000/μl) and strongly increased C-reactive protein (CRP > 50 mg/l), a history of diabetes mellitus, a history of neoplastic disease, a history of chronic kidney disease, peripheral vascular disease (PVD, Fontaine stage II or higher [6]), colonization with methicillin-resistant *Staphylococcus aureus* (MRSA), operating time, and radiation exposure. Furthermore, duration of antibiotic treatment (in weeks) and construct failure requiring revision surgery were recorded and compared between conventional and robot group.

Statistical analysis

Descriptive analyses were performed using chi tests [2]. Continuous variables were compared using *t* test with a significance level of <0.05. Outcomes were modeled using uni- and multivariable logistic regression. The entire analysis was performed using Stata version 13.1 (College Station, Texas). *p*-values < 0.05 were considered significant.

Results

Demographic variables

A total of 206 patients underwent surgery for spondylodiscitis, 127 of which were male (61.6%). Wound healing problems requiring revision occurred in 30 out of 206 patients (14.6%; Table 1). $n = 113$ patients (54.9%) were over 70 years of age. Upon univariate analysis, old age was a predictor of wound breakdown (OR 2.87; CI 95% 1.16–7.06; $p = 0.022$; Table 2).

Comorbidities

Diabetes was prevalent in 65 (31.6%) patients of our sample. Its presence was not associated with an increased rate of wound revisions (OR 1.55; CI 95% 0.69–3.44; $p = 0.28$; Table 2). Chronic kidney disease ($n = 52$, 25.2%; OR 1.91; CI 95% 0.84–4.33; $p = 0.12$), a history of cancer ($n = 23/164$; 14.0%; OR 0.95; CI 95% 0.30–2.97; $p = 0.93$), and peripheral artery disease (4.3% of patients; $n = 9/206$; (OR 1.71; CI 95% 0.34–8.73; $p = 0.51$) did not appear to affect wound revision rate.

Table 1 Baseline variables associated with wound revision

		No wound revision *n* (%)	Wound revision *n* (%)	Total *n* (%)	*p*-value
Sex	Male	112 (88.2%)	15 (11.8%)	127 (100%)	0.156
	Female	64 (81.0%)	15 (19.0%)	79 (100%)	
	Total	176 (85.4%)	30 (14.6%)	206 (100%)	
Robot surgery	No	86 (79.6%)	22 (20.4%)	108 (100%)	0.013
	Yes	90 (91.8%)	8 (8.2%)	98 (100%)	
	Total	176 (85.4%)	30 (14.6%)	206 (100%)	
Age (years)	<70	83 (92.2%)	7 (7.8%)	90 (100%)	0.018
	≥70	91 (80.5%)	22 (19.5%)	113 (100%)	
	Total	174 (85.7%)	29 (14.3%)	203 (100%)	
WBC	<11,000/μl	121 (87.1%)	18 (12.9%)	139 (100%)	0.202
	≥11,000/μl	48 (80.0%)	12 (20.0%)	60 (100%)	
	Total	169 (84.9%)	30 (15.1%)	199 (100%)	
CRP	<50 mg/l	56 (88.9%)	7 (11.1%)	63 (100%)	0.271
	≥50 mg/l	106 (82.8%)	22 (17.2%)	128 (100%)	
	Total	162 (84.8%)	29 (15.2%)	191 (100%)	
Obesity	No	163 (86.7%)	25 (13.3%)	188 (100%)	0.096
	Yes	13 (72.2%)	5 (27.8%)	18 (100%)	
	Total	176 (85.4%)	30 (14.6%)	206 (100%)	
Diabetes	No	123 (87.2%)	18 (12.8%)	141 (100%)	0.281
	Yes	53 (81.5%)	12 (18.5%)	65 (100%)	
	Total	176 (85.4%)	30 (14.6%)	206 (100%)	
Kidney disease	No	135 (87.7%)	19 (12.3%)	154 (100%)	0.119
	Yes	41 (78.8%)	11 (21.2%)	52 (100%)	
	Total	176 (85.4%)	30 (14.6%)	206 (100%)	
Periph. vascular disease	No	169 (85.8%)	28 (14.2%)	197 (100%)	0.505
	Yes	7 (77.8%)	2 (22.2%)	9 (100%)	
	Total	176 (85.4%)	30 (14.6%)	206 (100%)	
Monosegmental surgery	No	114 (85.7%)	19 (14.3%)	133 (100%)	0.879
	Yes	62 (84.9%)	11 (15.1%)	73 (100%)	
	Total	176 (85.4%)	30 (14.6%)	206 (100%)	
MRSA (+)	No	164 (87.2%)	24 (12.8%)	188 (100%)	0.012
	Yes	11 (64.7%)	6 (35.3%)	17 (100%)	
	Total	175 (85.4%)	30 (14.6%)	205 (100%)	
Decompression surgery	No	108 (87.8%)	15 (12.2%)	123 (100%)	0.12 (missing *n* = 10)
	Yes	58 (79.5%)	15 (20.5%)	73 (100%)	
	Total	166 (84.7%)	30 (15.3%)	196 (100%)	
Epidural abscess	No	140 (87.5%)	20 (12.5%)	160 (100%)	0.10 (missing *n* = 1)
	Yes	35 (77.8%)	10 (22.2%)	45 (100%)	
	Total	175 (100%)	30 (100%)	205 (100%)	

Table 2 Uni- and multivariable effects

	Univariate			Multivariate		
	OR	CI 95%	*p*-value	OR	CI 95%	*p*-value
Female sex	1.75	(0.80; 3.81)	0.16			
Robot	0.35	(0.15; 0.82)	*0.016*	0.39	(0.16; 0.94)	*0.035*
Age > 70	2.87	(1.16; 7.06)	*0.022*	2.35	(0.92; 5.96)	0.072
WBC > 11,000/μl	1.68	(0.75; 3.75)	0.21			
CRP > 50 mg/l	1.66	(0.67; 4.13)	0.28			
Obesity	2.51	(0.82; 7.64)	0.11			
Diabetes	1.55	(0.69; 3.44)	0.28			
Kidney failure	1.91	(0.84; 4.33)	0.12			
Periph. artery disease	1.71	(0.34; 8.73)	0.51			
Monosegmental surgery	1.07	(0.48; 2.38)	0.88			
Canal decompression	1.86	(0.85; 4.08)	0.12			
Spinal abscess	2.00	(0.86; 4.65)	0.11			
MRSA	3.73	(1.26; 11.01)	*0.017*	2.36	(0.71; 7.84)	0.161
History of neoplasia	0.95	(0.30; 2.97)	0.93			

Upon univariate analysis, potential factors associated with the need for surgical wound revision include old age, minimally invasive technique (using the robot in this case) and MRSA. After multivariate correction, only minimally invasive technique retained significance (values in italics)

Resistent bacteria

MRSA was identified as the pathogen for spondylodiscitis in 17 cases (8.3%). In this sample, we were able to detect a significant effect of the presence of MRSA on wound healing difficulty (OR 3.73; CI 95% 1.26–11.01; $p = 0.017$).

Surgical variables

Instrumentation spanned more than one segment in 133 cases (64.6%). No significant effect of the extent of surgery was found with the rate of wound healing problems (OR 1.07; CI 95% 0.48–2.38; $p = 0.88$). Minimally invasive technique with the aid of a robotic system was applied in 98 cases (47.6%). Decompression was performed in 70/196 cases (35.7%; missing $n = 10$). Wound revision was required in eight out of 98 patients (8.2%) in the robot group and 22/108 (20.4%) in the conventional surgery group. In the robotic group, wound healing problems were less frequent than in the conventional surgery group with an OR of 0.35 (CI 95% 0.15–0.92; $p = 0.016$). This finding was statistically significant (OR 0.35; CI 95% 0.14–0.82; $p = 0.016$; Table 2). Additional decompression was not significantly associated with the need for wound revision (OR 2.02; CI 95% 0.92–4.43; $p = 0.08$). The use of robot-assisted surgery remained significantly associated if adjusted for the use of additional decompression (OR 0.39; CI 95% 0.16–0.95; $p = 0.038$). In the monosegmental group, only 2/71 cases (2.8%) required surgical revision due to construct failure. In the plurisegmental group, this rate was higher (16/125 (12.8%); $p = 0.02$).

Spinal abscess and surgical spinal canal decompression

Spinal abscess was present in 45 cases of 205 (21.9%; missing value $n = 1$). In cases requiring wound revision, this figure was 33.3% (10 out of 30) while in patients without subsequent wound revision, this figure was 20.0% (35 out of 175). The difference was not significant ($p = 0.10$). Spinal abscess was significantly more frequent in the conventional group (32/108; 29.6%) compared to the robot group (13/97; 13.4%; $p = 0.005$).

Additional decompression of the spinal canal was carried out in 73/196 cases (37.2%; missing value $n = 10$). Decompression was carried out in 58/166 cases where no wound infection occurred (34.9%). It was performed in one half of cases requiring surgical wound revision (15/30; 50%). No statistical difference was found between groups ($p = 0.12$). Decompression surgery in addition to instrumentation was performed more frequently in the conventional surgery group (51/103; 49.5%) compared to the robot group (22/93; 23.7%; $p < 0.001$).

Multivariate model

In order to account for potential confounders in the analysis of predictive factors for wound healing difficulty, we built a predictive model including the variables which were associated with wound healing difficulty upon univariate analysis. Therefore, age > 70 years, the presence of MRSA, and robotic technique were included. The final analysis showed that only minimally invasive technique using robotic surgery remained as an independent predictor for lack of wound healing problems (Table 2).

Radiation exposure

Radiation exposure time was significantly lower in the robot group with a mean of 123 ± 86 s in comparison with a mean of 157 ± 99 s in the conventional group ($p = 0.014$; Table 3). For monosegmental surgeries, average radiation time was 105.1 ± 83 s while for multisegmental surgeries it was 161.4 ± 93.9 s ($p = 0.31$). For monosegmental surgeries alone, the robot group had an average fluoroscopy time of 97 ± 83 s compared to 145.0 ± seconds for plurisegmental surgery. In the conventional group, fluoroscopy times were 117.6 ± 82 s for monosegmental and 178.6 ± 101 s for multisegmental surgeries.

Construct failure

Construct failure occurred in 12/102 cases (11.7%) in the conventional and in 6/94 cases (6.4%) in the robot group ($p = 0.19$; $n = 10$ missing). The difference was not statistically significant (OR 0.51; CI 95% 0.18–1.42; $p = 0.20$).

Duration of antibiotic treatment

Antibiotic treatment was administered over an average of 10.1 ± 5.4 weeks in the conventional and 10.2 ± 4.3 weeks in the robot group ($p = 0.96$). Patients undergoing monosegmental surgery had a mean duration of 10.4 ± 5.4 weeks of antibiotic treatment while those with plurisegmental procedures had a duration of treatment of 9.8 ± 3.5 weeks ($p = 0.23$).

Discussion

At our institution, patients with spondylodiscitis routinely undergo surgical instrumentation. However, because of a florid systemic infection, one out of every seven operated patients required revision surgery due to wound healing problems despite ongoing antibiotic treatment. We found that the use of robotic assistance which facilitated the implementation of minimally invasive instrumentation at our center was associated with a significantly lower rate of wound healing problems in this fragile patient population.

Surgical variables

Minimally invasive techniques have allowed to further minimize the rate of surgical site infections and the need for wound revisions [17, 20]. In our series, minimally invasive pedicle screw fixation was performed using a robotic system [25]. Any other minimally invasive technique may have led to similar results. The robotic system was applied in about one half of surgeries while the remaining cases were operated using conventional open technique. Overall, the rate of wound revisions in the conventional group was higher compared with cases where robot-assisted minimally invasive technique was used. This effect persisted as the only independent predictor of wound healing capacity after multivariate analysis. This finding in our large series corroborates the notion that implementation of minimally invasive surgical technique is one of the leading modifiable variables to achieve satisfactory wound healing. The choice of a specific technique of minimally invasive surgery—robot, navigation, or fluoroscopy—is likely secondary.

While the need for additional decompression surgery showed a tendency towards an association with wound healing difficulties, minimally invasive surgery was the most important predictor for wound healing even after multivariate adjustment. Although the overall duration of antibiotic treatment of about 10 weeks was not different between the conventional and robot-assisted surgery group, the higher rate of revision surgeries in the first remains an argument in favor of minimally invasive surgery. Moreover, the rate of long-term construct failure was not significantly different between conventional and robot-assisted surgery groups. Of note, we performed an internal validation which confirmed that construct failures were five times more likely when instrumentation spanned more than one segment. In our center, minimally invasive surgeries are carried out using robotic assistance. However, whether minimally invasive technique is achieved using robotic technique, standard fluoroscopic technique or other auxiliary measures is probably not important. Robotic technique has its disadvantages such as a learning curve and initially longer operating times [24].

Radiation

One of the potential drawbacks of minimally invasive techniques is that it may increase radiation exposure. Therefore,

Table 3 Radiation dose

	Conventional Mean ± SD	Robotic Mean ± SD	Total Mean ± SD	*p*-value
No. of operated levels	3.0 ± 1.9	2.3 ± 1.6	2.7 ± 1.8	0.001
Duration of surgery	219.0 ± 89.0	184.3 ± 87.2	200.9 ± 89.5	0.003
Fluoroscopy time (s)	157.13 ± 98.99	123.65 ± 86.68	138.76 ± 93.65	0.014
Radiation (mAs)	4.039 ± 8.816	3.404 ± 3.628	3.688 ± 6.466	0.057

we included radiation parameters in this study. The use of image-guided surgery is known to reduce the need for intraoperative use of C-arm fluoroscopy [30]. Our study also showed a decreased radiation exposure when using the robot. While average fluoroscopy times are in the higher range with over 100 s per segment, reported values range up to 147 s per instrumented level in the literature [14]. Reduced radiation exposure when using robotic guidance has been reported previously [23]. The increasing awareness of radiation-related health hazards in medical professionals may be an additional argument to consider image-guidance—and in this case—robot-guidance [10].

Demographic variables

With increasing age, the risk of surgical site infections rises [5]. This has been attributed to a decrease in metabolism, immune responses, and a delay in epithelialization. Wound closure takes about 2 days longer in the elderly than in younger individuals [12]. Our data confirmed this notion. Upon univariate analysis, age greater than 70 years was a predictor of wound breakdown.

Comorbidities

Obesity is a well-known risk factor for surgical site infections [22]. It is associated with an increased general inflammatory state in the body with dysregulation of cytokine secretion [4] and impaired cellular immune responses [19]. Wound healing of obese patients undergoing complex spinal surgery for pyogenic spondylodiscitis will thus require special attention. While our data showed some effect of obesity with an odds ratio of about 2.5, our series failed to demonstrate a significant association with wound breakdown. Therefore, larger patient numbers may be required to assess the true effect strength. However, in the absence of a prospective trial on the subject, our data remain the only source of information on wound breakdown in this population of patients.

Diabetes affected about one third of patients in our study. However, contrary to our expectations, [21] diabetes was not associated with an increased rate of wound revision. A recent series showed that in spinal arthrodesis, the presence of diabetes was associated with a staggering 30% risk of surgical site infection compared to 11% in non-diabetic patients [3]. The principal difference between their and our series is the presence of an active infection and an already immune-compromised population. In pyogenic spondylodiscitis, immune responses may be reduced for several reasons besides diabetes.

Chronic kidney disease, although contributing to increased readmissions for other orthopedic indications, [18] and peripheral vascular disease did not affect wound revision rates in our series, suggesting that chronic kidney disease nor peripheral artery disease should not affect the decision to provide surgical treatment for spondylodiscitis.

Laboratory values

Since the goal of surgery is to reduce the infectious load and prevent or limit septic dissemination of the disease, preoperative laboratory values are unlikely to influence the decision to treat.

Resistent bacteria

Surgical site infections with multiresistant bacteria constitute a major surgical problem because of the limited choice of effective antibiotics [9]. So far, only one study has explicitly addressed the challenges posed by multiresistant germs in pyogenic spondylodiscitis [26]. Methicillin-resistant *Staphylococcus aureus* is the pathogen in two thirds of all multiresistant cases of spondylodiscitis in the aforementioned German study population [26]. Although the choice of antibiotics and germ containment remain difficult issues, our analysis showed that MRSA appears to be an important contributor to wound healing problems after instrumentation for spondylodiscitis.

Limitations

If analyzed between subgroups, i.e., patient sample with and without decompression for strata of robotic technique, the main finding of the study could not be reproduced. The small number of measured primary outcome event (wound revision) in the subgroup may be an explanation reason for this finding. In the latter case, the same analysis would need to be rerun in a larger sample which will likely remain elusive for some time. Another reason reside within the fact that our initial analysis was biased towards less invasive surgery in the robot group. Although we attempted to rule this out by a multivariate analysis, the generalizability of our findings remains limited. The study was retrospective. Although we formulated a hypothesis and data handling algorithm prior to data acquisition and analysis, we cannot rule out a bias in patient distribution between conventional versus robot groups. On the other hand, it is difficult to obtain such a large data sample on a heterogeneous disease from a "clean" prospective trial with strict inclusion and exclusion criteria.

The primary outcome parameter of this study was the need for a surgical wound revision. While this parameter is neither a direct surrogate for treatment success or health, it might be a useful variable to identify some finer differences between surgical techniques. Adherence to antibiotic regimen and long-term infection control or quality of life are more difficult to assess in a uniform manner.

Conclusions

The use of robotic minimally invasive technique was associated with a significantly lower wound healing problems and lower intraoperative radiation exposure. Other variables such as older age and MRSA infection were predictive of wound breakdown in univariate, but not multivariate analysis. Therefore, our data suggest that the main modifiable factor to achieve improved wound healing resides within the implementation of minimally invasive surgery, in our case with the help of robotic guidance.

Compliance with ethical standards

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Conflict of interest The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. For this type of study, formal consent is not required.

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